

Selected Papers of Beijing Forum 2008

Possible Links Between Human Activities and the Earth's Climate

Teruyuki Nakajima

Professor, The University of Tokyo

Abstract

In this article I like to overview several important climate effects of aerosols that can change the earth's radiation budget, cloud, and also precipitation. There are still large uncertainties in evaluation of these effects by models and observation. I like to propose recommendations for future works to reduce the large uncertainties. Especially a future important work is to improve fine resolution aerosol and cloud modeling and combined analysis of satellite and surface data.

Keywords: Ancient Greece; agon; agonal spirit

1. Introduction

Anthropogenic short-lived atmospheric constituents such as aerosols can make significant effects on the earth's climate, especially in the Asian region with large aerosol emission sources, of which forcing is comparable to that of long-lived greenhouse gases but with opposite sign and different geographical distributions (e.g., Forster et al., 2007). Recent studies have found that various climate effects of aerosols are possible. The aerosol direct effect is that aerosols directly scatter and absorb/emit radiation, through which the earth's radiation budget can be modified. There are several evidences that the solar radiation at the earth's surface undergoes a significant long-term trend in the last several decades, indicating a surface dimming effect in the polluted areas. At the same time, aerosols are found to cause various indirect effects to change the radiation budget, temperature, cloudiness, precipitation etc. A well known indirect effect is called the first indirect effect or Twomey effect (Twomey et al., 1984) that causes an increase in the cloud optical thickness (COT) when aerosols act as cloud condensation nuclei (CCN) to increase the cloud droplet number and hence to decrease the effective cloud droplet radius (CDR) when the total liquid water path (LWP) of the cloud does not change. The secondary indirect effect or Albrecht effect (Albrecht, 1989) is also recognized as important because this effect significantly increases LWP and hence increases COT when aerosols reduce CDR to lower the precipitation efficiency of the cloud layer. Recent studies also show significant cloud and precipitation changes can be produced by aerosol indirect effects of various kinds (e.g., Rosenfeld, 2000; Chung and Ramanathan, 2007; Mukai et al., 2008).

In this study we like to overview these various mechanisms from view point of modeling and observation. Issues are: what are the optical properties of aerosols; what is the role of CCN in the cloud formation process in different regions; how greenhouse gases and aerosols can compete to change the surface temperature and cause a secondary general circulation to produce a precipitation change on global scale.

2. Aerosol characteristics and direct radioactive forcing

Global dimming and brightening phenomena have been studied using data of surface radiation networks (Wild et al., 2005; Che et al., 2005; Qian et al., 2006). These studies showed that the surface solar radiation is increasing in the European region, while the Asian region still suffers a decrease in the surface solar radiation due to increasing anthropogenic aerosols. Future trend of anthropogenic aerosol change depends on the future economical growth and actions for reducing air pollution in this region. Surface pyranometer and pyrliometer networks of GEWEX/BSRN and of each country, especially that of Chinese Meteorological Administration covering a large area, are useful for long-term monitoring of the surface radiation flux and equivalent aerosol optical thickness (AOT) for several decades. These data are combined with satellite remote sensing, such as NOAA AVHRR and EOS MODIS, for depicting prevailing aerosol plumes over Asian regions.

One of important parameters for determining surface and TOA (the top of the atmosphere) radiation budget is the single scattering albedo, SSA, defined as the ratio between scattering and extinction cross sections. The SSA value is strongly controlled by the black carbon content of aerosols. Also mineral dust particles are predominant in the springtime to affect the value of SSA in the East Asian region. Hence the aerosol optical properties in this region are very complicated (Clarke et al., 2004). In order to elucidate the optical and radiative properties of Asian aerosols, large scale comprehensive regional experiments have been performed: INDOEX, ACE-Asia, APEX, ABC-EAREX & APMEX, EAST-AIRE, Pearl River Delta Experiment, and others. Nakajima et al. (2007) showed that the radiative efficiency factor, defined as $\beta = -\Delta F / \Delta \tau_{500}$ where ΔF is the 24 hour solar radiative forcing of aerosol and $\Delta \tau_{500}$ is the AOT at wavelength of 500nm, can reach a value as large as 100 in the case of Asian dust events, which is very large compared with a mean value around 70 as reported by many other studies (Nakajima et al., 2007). They showed such large forcing efficiency can be produced when soot particles adhere on the surface of coarse mineral dust particles. Another possibility for such a large β -value is that mineral dust particles themselves are highly absorbing as suggested by several past studies (Sokolik and Toon, 1999; Aoki et al., 2005).

In spite of these past studies, we still need to improve our model to relate aerosol chemical characteristics with their AOT, SSA, asymmetry parameter which is the first angular moment of the scattering phase function, and radiative efficiency factor. A simple internal and external homogeneous mixture seems to be not a good approximation. A recent study showed that black carbon particles evolve into larger particles with time during transportation (Moteki et al., 2007).

3. Cloud field perturbation and possible climate effects

It has been a common recognition that direct and indirect effects of aerosols at TOA reduce the available solar energy and significantly offset the global warming by increasing greenhouse gas concentration. On the other hand, it is still needed to study how the regional climate is perturbed by aerosols. Past studies have shown that there is a long-term trend in the cloud amount over China (Kaiser et al., 2002). Several reasons are possible for this regional cloud change. Global warming phenomenon can cause a change in the global circulation and land-ocean temperature gradient causing a change in Monsoon circulation. Change in the land use and vegetation distribution can cause perturbation to the soil moisture and vertical atmospheric stability. From these mechanisms a significant change in the cloud amount is expected.

Along with these effects, anthropogenic aerosols can generate a large scale circulation change and hence cloud amount change as discussed by Mukai et al. (2007). They found observed trend of cloud amount change over China can be explained by competing effects of greenhouse gas effect and aerosol effect. The latter effect can be further divided into two mechanisms: One is a change of local cloudiness by regional direct and indirect aerosol forcing. Direct forcing cools the surface of the region and hence the atmospheric stability is changed. At the same time, aerosols act as CCN to increase the cloud amount through the secondary indirect effect which increases the cloud lifetime. The second effect is that the large scale general circulation is changed when the surface of the region is cooled by aerosols through direct and indirect surface forcing. Figure 1 illustrate these effects. Simulations by a general circulation model, which is coupled with a mixed-layer ocean model, suggested that cloud and precipitation can be changed even over tropical region (Takemura et al., 2005; Mukai et al., 2007). And the simulation results also showed that the dominant mechanism for the change in China is different in northern part, eastern part, and

southern part of China as shown in Figure 2. So the interpretation of the observed change of cloud amounts for low,

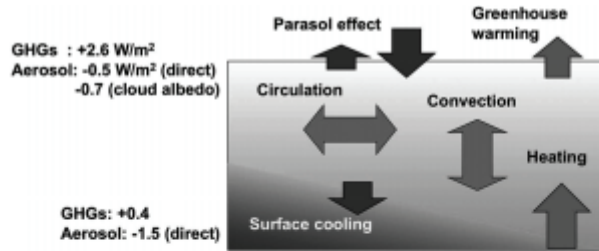


Figure 1 Greenhouse warming by greenhouse gases and various indirect forcings of aerosols. Surface cooling of aerosols can change global scale circulation and convection.

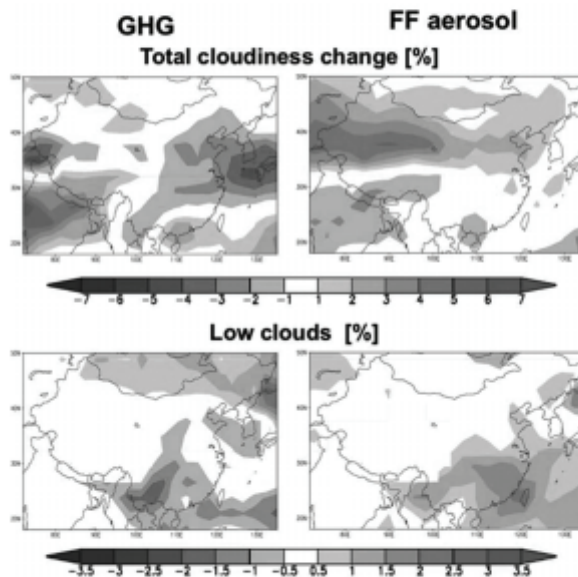


Figure 2 Changes in total cloudiness and low-level clouds between current and pre-industrial eras. An atmospheric GCM is coupled with a mixed ocean model for simulating an aerosol indirect effects through cloud microphysics change, the sea surface temperature change, and so on.

middle, and high level clouds is very complicated and we need more validation study.

Useful data for validation are distributions of AOT, COT, CDR, and LWP from satellite remote sensing (e.g., Kawamoto et al., 2004). It should be recognized, however, that the existing satellite data analyses showed a large variety in the dependence of the cloud parameters on the aerosol index (Nakajima and Schultz, 2008). It is, therefore, we also need more elaboration of satellite data analysis.

4. Conclusions and Recommendation for future tasks

The following conclusions and recommendations are drawn from this study:

- (1) Aerosols have many pathways to change the regional climate. Our understanding level of each process is not high.
- (2) One of important aerosol effects is an indirect effect through change in the earth's surface temperature and general circulation.

(3) Observed long-term trend of regional geophysical parameters (cloud amount, cloud properties, precipitation, and so on) needs to be interpreted as the total effect of global warming, aerosol effect and others. It is, therefore, we need comprehensive and careful model simulations and data analysis to understand the change.

In order to overcome the above-listed problems, the following works have to be done:

(a) Physical and chemical modeling of aerosol properties and radiative effect must be improved. Such improvements should be supported by more measurements and laboratory experiments.

(b) Regional and global simulations making use of non-hydrostatic meso-scale models are needed to understand the mechanism of the regional climate change. In this regard, models have to be improved for better simulation of cloud formation process and aerosol-cloud interaction process. Especially deep cloud modeling is important.

(c) Collaboration and coordinated effort are needed for improving Asian networks of aerosol, cloud, and radiation measurements. Data exchange and collaboration for data analyses are very important, because comprehensive analyses need efforts by researchers in different fields, i.e., atmospheric dynamics, physics, and chemistry.

References

- Albrecht, B. A., 1989: Aerosols, cloud microphysics, and fractional cloudiness, *Science*, 245, 1227-1230.
- Aoki, T., T. Y. Tanaka, A. Uchiyama, M. Chiba, M. Mikami, and S. Yabuki, 2005: Sensitivity experiments of direct radiative forcing caused by mineral dust simulated with a chemical transport model, *J. Meteorol. Soc. Japan*, 83A, 315-331.
- Che, H. Z., G. Y. Shi, X. Y. Zhang, R. Arimoto, J. Q. Zhao, L. Xu, B. Wang, and Z. H. Chen, 2005: Analysis of 40 years of solar radiation data from China, 1961-2000, *Geophys. Res. Lett.*, 32, L06803, doi:10.1029/2004GL022322.
- Chung, C. E., and V. Ramanathan, 2007: Relationship between trends in land precipitation and tropical SST gradient, *Geophys. Res. Lett.*, 34, L16809, doi:10.1029/2007GL030491.
- Clarke, A. D., et al., 2004: Size distributions and mixtures of dust and black carbon aerosol in Asian outflow: Physiochemistry and optical properties, *J. Geophys. Res.*, 109, D15S09, doi:10.1029/2003JD004378.
- Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz, and R.V. Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, Cambridge University Press, United Kingdom and New York, NY, USA.
- Kaiser, D. P., and Y. Qian, 2002: Decreasing trends in sunshine duration over China for 1954-1998: Indication of increased haze pollution?, *Geophys. Res. Lett.*, 29, 2042, doi:10.1029/2002GL016057.
- Kawamoto, K., T. Hayasaka, T. Nakajima, D. Streets, and J.-H. Woo, 2004: Examining the aerosol indirect effect using SO₂ emission inventory over China using SO₂ emission inventory. *Atmos. Res.*, 72, 353-363.
- Moteki, N., Y. Kondo, Y. Miyazaki, N. Takegawa, Y. Komazaki, G. Kurata, T. Shirai, D.R. Blake, T. Miyakawa, and M. Koike, 2007: Evolution of mixing state of black carbon particles: Aircraft measurements over the western Pacific in March 2004, *Geophys. Res. Lett.*, 34, L11803, doi:10.1029/2006GL028943.
- Mukai, M., T. Nakajima, and T. Takemura, 2008: A study of anthropogenic impacts of the radiation budget and the cloud field in East Asia based on model simulations with GCM, *J. Geophys. Res.*, 113, D12211, doi:10.1029/2007JD009325.
- Nakajima, T., and M. Schulz, 2008: What do we know about large-scale changes of aerosols, clouds, and the radiation budget?, in *Perturbed Clouds in the Climate System*, Eds. J. Heintzenberg and R.J. Charlson, FIAS Forum, to be published.
- Nakajima, T., S.-C. Yoon, V. Ramanathan, G.-Y. Shi, T. Takemura, A. Higurashi, T. Takamura, K. Aoki, B.-J. Sohn, S.-W. Kim, H. Tsuruta, N. Sugimoto, A. Shimizu, H. Tanimoto, Y. Sawa, N.-H. Lin, C.-T. Lee, D. Goto, and N. Schutgens, 2007: Overview of the Atmospheric Brown Cloud East Asian Regional Experiment 2005 and a study of the aerosol direct radiative forcing in east Asia, *J. Geophys. Res.*, 112, D24S91, doi:10.1029/2007JD009009.
- Qian, Y., D.P. Kaiser, L.R. Leung, and M. Xu, 2006: More frequent cloud-free sky and less surface solar radiation in China from 1955 to 2000. Rosenfeld, D., 2000: Suppression of rain and snow by urban and industrial air pollution, *Science*, 287, 1793-1796.
- Schulz, M., C. Textor, S. Kinne, Y. Balkanski, S. Bauer, T. Berntsen, T. Berglen, O. Boucher, F. Dentener, S. Guibert, I. S. A. Isaksen, T. Iversen, D. Koch, A. Kirkevåg, X. Liu, V. Montanaro, G. Myhre, J. E. Penner, G. Pitari, S. Reddy, Ø. Selund, P. Stier, and T. Takemura, 2006: Radiative forcing by aerosols as derived from the AeroCom present-day and pre-industrial simulations. *Atmos. Phys. Chem. Discuss.*, 6, 5095-5136.
- Sokolik I.N., and O.B. Toon, 1999: Incorporation of mineralogical composition into models of the radiative properties of mineral aerosol from UV to IR wavelengths, *J. Geophys. Res.*, 104, 9423-9444.
- Takemura, T., T. Nozawa, S. Emori, T.Y. Nakajima, and T. Nakajima, 2005: Simulation of climate response to aerosol direct and indirect effects with aerosol transport-radiation model. *J. Geophys. Res.*, doi:10.1029/2004JD005029.
- Twomey, S., M. Piepgrass and T. L. Wolfe, 1984: An assessment of the impact of pollution on global cloud albedo. *Tellus*, 36B, 356-366.

Wild, M., H. Gilgen, A. Roesch, A. Ohmura, C. N. Long, E. G. Dutton, B. Forgan, A. Kallis, V. Russak, and A. Tsvetkov, 2005: From dimming to brightening: Decadal changes in solar radiation at earth's surface, *Science*, 308, 847-850, doi: 10.1126/science.1103215.